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1. Your reference	IP/P7295	0316402.7
2. Patent application number *(The Patent Office will fill in this part)*	12 JUL 2003	~~14JUL03 E822316-1 D02776~~ P01/7700 0.00-0316402.7
3. Full name, address and postcode of the or of each applicant *(underline all surnames)*	QINETIQ LIMITED Registered Office 85 Buckingham Gate London SW1E 6PD United Kingdom	
Patents ADP number *(if you know it)*		
If the applicant is a corporate body, give the country/state of its incorporation	GB	~~8183873008~~ 08183857001
4. Title of the invention	Direction Finding	
5. Name of your agent *(if you have one)*	Bowdery Anthony Oliver	
"Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*	QINETIQ LIMITED IP Formalities A4 Bldg Cody Technology Park Ively Road Farnborough Hants GU14 0LX United Kingdom	8183873005
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11. I / We request the grant of a patent on the basis of this application.

Signature Mr A W S Williams   Date 11 July 2003

12. Name and daytime telephone number of person to contact in the United Kingdom   Mrs Linda Bruckshaw 01252 392722

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Direction Finding

This invention relates to direction finding, and more particularly to direction finding using radio techniques.

Direction finding by radio is known. In a direction finding system having a number of separate antennas, radio wavefronts reach the antennas with different delays. Assuming the wavefronts have narrow bandwidth, these delays give rise solely to relative phase shifts. For determining the directions or bearings of M-1 radio frequency (RF) emitters (M is a positive integer), a typical direction finding system employs M antennas, a respective receiver for each antenna, and processing circuitry for each receiver. The processing circuitry implements a discrete Fourier transform to divide its respective signal into frequency bins or channels. Signals are then combined in pairs, and for each channel a respective covariance matrix is constructed from which emitter bearings are estimated. This approach suffers from the problem of requiring as many receivers as there are antennas, receivers being expensive and bulky. It is unsuitable for example for man-portable equipment or for mounting in small aircraft.

To get round the multiple receiver problem, it has been proposed to use a single port receiver, spatial spectrum estimation technology, and a weight perturbation algorithm to obtain the covariance matrix. See Zhao Yimin, "A Single Port Receiver Spatial Spectrum Estimate DF System", 0-7803-3216-4/96 IEEE 1996. This is however a relatively complex approach to the problem.

It has also been proposed to combine RF antenna signals in beamformers and use a single receiver connected to successive beamformers via a multipole switch, one pole per beamformer. See C M S See, "High Resolution DF with a Single Channel Receiver", 0-7803-7011-2/01 IEEE 2001. A single spatial covariance matrix is formed, and the bearings or directions of up to M-1 emitters can be estimated, where M is the number of antennas. This requires M^2 beamformers, another source of expense and bulk.

Another solution is adopted in the Rohde & Shwartz DDF 195 instrument, which combines pairs of RF antenna signals with each of four relative phase shifts inserted between them in

succession by means of switches This requires only a single receiver, and uses one antenna as a reference antenna, combining its output with that of other antennas in turn with multiple switched phase shifts. However, the method is for estimating the bearing of a single emitter only. A patents search has indicated that the following patent documents EP455102, DE4014407, DE3636630, DE19529271 and DE2723746 are related to direction finding.

US patent application no. US 2002/0190902 A1 describes sampling RF signals from M antennas at a sampling rate equal to or greater than the signal bandwidth multiplied by 2M. This is followed by Fourier transformation of resulting signal samples to provide spectra. Direction finding is then based on line configuration in the spectra and associated phase and amplitude data. It employs a multiplicity of directional antennas to provide beamforming.

It is an object of the present invention to provide an alternative form of direction finding.

The present invention provides a direction finding system incorporating a plurality of antennas characterised in that the system also includes:

a) means for determining individual antenna signal strengths;

b) combining means for determining combined antenna signal strengths by forming combinations of first and second antenna signals derived from different antennas, wherein the second antenna signals are in two sets with signals in one set having a non-zero phase difference relative to signals the other set; and

c) means for deriving covariance matrix elements from antenna signal strengths and for determining at least one emitter bearing therefrom.

The invention provides the advantage of requiring only a single receiver when successive signal strengths are determined in successive steps, which reduces cost and bulk and still provides a viable direction finding technique.

The relative phase difference may be in the range 30 to 120 degrees, preferably substantially 90 degrees.

The combining means may be arranged to combine antenna signals with equal gain magnitude and with equal and unequal phase. It may incorporate phase shifting means switchable into and out of an antenna signal path, and an adder having two inputs both switchably connected to individual signal paths extending to respective antennas.

The means for determining individual antenna signal strengths may comprise a first multipole switch having input poles connected to receive signals from respective antennas; the combining means may incorporate a second multipole switch having input poles connected to receive signals from respective antennas and a third multipole switch for switching phase shifting means into and out of an antenna signal path extending via the second multipole switch; and the combining means may also incorporate adding means for combining signals, the adding means being arranged to add an antenna signal in a first signal path extending via the first multipole switch to another antenna signal in a second signal path extending via the second and third multipole switches.

In another aspect, the present invention provides a method of direction finding using a plurality of antennas characterised in that the method incorporates:

a) determining individual antenna signal strengths;

b) determining combined antenna signal strengths by forming combinations of first and second antenna signals derived from different antennas, wherein the second antenna signals are in two sets with signals in one set having a non-zero phase difference relative to signals the other set; and

c) deriving covariance matrix elements from antenna signal strengths and determining at least one emitter bearing therefrom.

The relative phase difference may be in the range 30 to 120 degrees, preferably substantially 90 degrees, and successive signal strengths may be determined in successive steps.

The step of forming combined antenna signal strengths combines antenna signals with equal gain magnitude and with equal and unequal phase. It may include switching phase

shifting means into and out of an antenna signal path, and adding signals in signal paths extending switchably to different antennas.

The step of determining individual antenna signal strengths may comprise switching signals from antennas via a first path. The step of forming combined antenna signal strengths may incorporate:

a) switching signals from antennas via a first path for combining;

b) switching signals from antennas via a switch selectable second path or a third path for combining, the third path being arranged to phase shift antenna signals therein relative to antenna signals in the second path; and

c) adding a first path antenna signal to second and third path antenna signals individually.

In order that the invention might be more fully understood, embodiments of the invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

Figure 1 is a schematic block diagram of a direction finding system of the invention;

Figure 2 is a graph illustrating direction finding results obtained using the invention;

Figure 3 is a graph illustrating direction finding results obtained using a single receiver prior art system comparable with the invention; and

Figure 4 is a graph illustrating direction finding results obtained using a multiple receiver prior art system;

Referring to Figure 1, a direction finding system of the invention is indicated generally by 10. As illustrated for the purposes of this example, the system 10 incorporates four antennas 12 each of which is conventional i.e. omnidirectional. In general, as many antennas may be used as are required to detect a desired number of emitters, i.e. M antennas for M-1 emitters. Signals pass from the antennas 12 via respective buffer amplifiers 14 to first and second multipole switches SW1 and SW2, the amplifiers 12 being connected to respective input poles b, c, d and e of both switches. The multipole switches SW1 and SW2 have respective movable contacts C1, C2 which allow any of the associated input poles b to d in each case to be connected to respective output poles f.

The output pole f of the first switch SW1 is connected to a first phase shifter P1 introducing a phase shift of ϕ_1, and the output pole f of the second switch SW2 is connected to second and third phase shifters P2 and P3 introducing phase shifts of ϕ_2 and ϕ_3 respectively. In the present example, where an ideal situation is envisaged, all three phase shifters P1 to P3 have a gain of unity: the first and second phase shifts ϕ_1 and ϕ_2 are zero (and the associated phase shifters P1 and P2 could be removed and replaced by connections), and the third phase shift ϕ_3 is 90 degrees. However, non-ideal gains/phases can be accommodated by calibration (as will be described later). Satisfactory performance has been demonstrated with errors up to plus or minus 60 degrees: in other words the phase difference ϕ_3 introduced by the third phase shifter P3 may be anything in the range ±30 to ±120 degrees, with simultaneous gain discrepancy of up to 3 dB compared to unity. Larger discrepancies result in progressive deterioration of performance. This implies the third phase shifter P3 providing for ϕ_3 to be preferably in the range 30 to 120 degrees different to ϕ_2 but ϕ_1 is unrestricted. It is also acceptable for phase shift and gain to vary with frequency, provided the phase shift is reasonably close to 90 degrees and phase shifter gains are reasonably close to 1.0, and that these parameters are stable and predetermined functions of frequency.

An output signal from the first phase shifter P1 passes to a first input 16a of an adder 18. Output signals from the second and third phase shifters P2 and P3 pass to first and second input poles p and q respectively of a third multipole switch SW3, which has a third input pole r connected to ground. The third switch SW3 has a movable contact C3 which allows any of the associated input poles p, q and r to be connected to an output pole z, which in turn is connected to a second input 16b of the adder 18.

Figure 1 is a somewhat idealised drawing in which all components are assumed to be perfect and (where appropriate) matched. In practice, in a non-ideal situation, components may need to be trimmed or impedance matched to counteract unwanted effects by inserting additional circuitry. This is well known in the art of electronics and will not be described.

The adder 18 has an output 20 connected to a series-connected chain of elements consisting of a receiver 22, an analogue to digital converter (ADC) 24, a discrete Fourier transformer 26 and a digital signal processor (DSP) 28. The digital elements 24 to 28 may

be replaced by equivalent analogue processing if desired. The transformer 26 provides a discrete Fourier transform (DFT) of length N points with windowing. This is a well-known calculation and will not be described: see e.g. A V Oppenheim and R W Schafer with J.R. Buck, "Discrete Time Signal Processing", Prentice Hall, Englewood Cliffs, NJ. USA, 1999. The DFT is advantageously computed by fast Fourier transform (FFT), but this is not essential. The choice N=1 corresponds to the trivial case equivalent to no discrete Fourier transform present.

The direction finding system 10 operates as follows. By appropriate choice of the positions of the movable switch contacts C1 to C3, any antenna signal may be added to any other antenna signal, or selected alone by adding it to a zero signal at grounded input r of third switch SW3. Assuming that the three phase shifters P1 to P3 have equal gain magnitudes, antenna signals at the adder inputs 16a and 16b have a relative phase shift between them equal to ϕ_1-ϕ_2 or ϕ_1-ϕ_3 according to whether the third switch movable contact C3 is connected to its first or second input pole p or q respectively. In the ideal case, $\phi_1 = \phi_2 = 0$ and $\phi_3 = 90$ degrees. In this case, the relative phase shift is 0 or 90 degrees (ignoring sign) between adder input signals according to whether the third switch movable contact C3 is connected to its first or second input pole p or q.

The receiver 22 has a front-end bandpass filter (not shown) to attenuate unwanted signals outside a frequency band in which the antenna signals appear. It processes the adder output signal and converts it to a complex output in a base band convenient for sampling and analogue to digital conversion at 24. The sampling rate of the ADC 24 must be sufficiently high to avoid aliasing, i.e. it must exceed the bandwidth of the receiver front-end bandpass filter. If, for example, the front-end bandwidth is 25 MHz, and a 512-point DFT is implemented by the transformer 26, the ADC sampling rate would be at least 27.5MHz, and it would take approximately 20 μs to acquire 512 samples for the transformer 26. The digital signal from the ADC 24 is converted by the transformer 26 into a spectrum in terms of a set of frequencies expressed as bins or channels of finite width each with an associated magnitude. The frequency channels would be approximately 100 kHz wide for a 512 point DFT with sampling at 27.5MHz. A DFT is implemented with windowing to reduce leakage between channels. The options for choice of window include a rectangular window equivalent to no window.

Optionally, selection of settings of movable contacts C1 to C3 may be made in such a way that not all antennas contribute. This gives faster processing, but possibly less accuracy, and it reduces the maximum number of emitters that can be detected.

As has been mentioned, the various possible settings of the switches SW1, SW2 and SW3 allow the receiver 22 to input either the signal from any individual antenna 12, or a sum of relatively phase shifted signals from any pair of antennas 12. The switches SW1 to SW3 may be operated to give a random or pseudo-random selection of antenna signals to avoid possible deleterious effects with particular signals. The output of the receiver 22 is sampled by the ADC 24 and processed by the transformer 26, which computes the N-point windowed DFT of a block of N consecutive samples from the ADC. This is a well known procedure and will not be described in detail: The output of the transformer 26 comprises N frequency domain samples, i.e. magnitudes of the contents of the N frequency bins. For the general or nth frequency bin, the frequency domain sample is denoted by S^n, where n is a frequency domain index in the range 0 to N-1). S_k^n is defined as the discrete Fourier transformer output with frequency index n if the kth antenna is connected through the first switch SW1, the third switch SW3 is connected to 0V at r, and the gain of the entire path from the kth antenna to the receiver input is unity.

The process of direction finding consists of estimating the bearing or angle of incidence or angle of arrival of one or more signals received by the antennas 12. It is carried out for one or more frequency bins by the digital signal processor (DSP) 28, which processes frequency domain samples S^n.

A complex gain constant G_{1k} is now defined to represent both gain and phase shift applied to an antenna signal in a path from the kth antenna 12 (k = 1 to M), through the first switch SW1, the first phase shifter P1 and the adder 20 to the receiver 22. If the buffer amplifiers 14 have equal gains, and input poles b to d of the first switch SW1 have like properties, then G_{1k} has the same value for all antennas 12 and is written G_1. If the gains of the buffer amplifiers 14 are not equal, or the first switch SW1 properties vary between inputs, the value of G_{1k} will be different for each antenna 12. To simply analysis, these gains are assumed to be equal for all antennas 12: If they are not in fact equal, the term G_1 should be

replaced by G_{1k} in the analysis below, which is then carried out for each antenna 12 separately.

Similarly, complex gain constants G_{2Ak} and G_{2Bk} are now defined to represent both gain and phase shift applied to an antenna signal in paths to the receiver 22 from the kth antenna 12 via (*inter alia*) the second and third phase shifters P2 and P3 respectively. Again, G_{2Ak} and G_{2Bk} are assumed to be the same for all antennas 12, and are written G_{2A} and G_{2B} respectively. As before, if this assumption is untrue, the gains should be replaced by G_{2Ak} and G_{2Bk} and the analysis carried out for each antenna 12.

The gain of the combination of the receiver 22, ADC 24 and transformer 26 do not affect the direction finding result, so to simplify analysis without affecting results this gain is assumed to be unity.

The gains G_1, G_{2A} and G_{2B} are first measured at every frequency of interest, i.e. at the centre frequencies of those frequency bins defined by the DFT operation in the transformer 26 which are associated with emitters. With the first switch SW1 connected to the buffer amplifier 14 of the kth antenna and the third switch SW3 connected to 0V at r, the transformer output with frequency index n is the product $G_1 S_k^n$. This transformer output has a mean squared value or power P_{kk} associated with the kth antenna and given by:

$$P_{kk} = E\{|G_1 S_k^n|^2\} = |G_1|^2 E\{|S_k^n|^2\} \qquad (1)$$

where E{..} is the mathematical expectation operator and |...| (as in e.g. $|S_k^n|$) represents a modulus. The DSP 28 computes a measurement (or "estimate") of P_{kk} which equals either a single value of S^n or an average or weighted average of several values of S^n, these values being obtained from the discrete Fourier transforms of respective blocks of data collected with switch contacts C1 to C3 set to appropriate positions. These blocks of data may be overlapping or non-overlapping. For clarity in the following explanation, P_{kk} will denote the measurement of P_{kk} obtained as described above.

The first switch SW1 is connected to the buffer amplifier 14 of each antenna 12 in turn, i.e. the antenna index k goes from 1 to M where M is the number of antennas, and the third switch SW3 remains connected to 0V at r. The transformer output power P_{kk} is measured in each case. $E\{|S_k^n|^2\}$ is then computed for each antenna 12 using the previously measured value of G_1 as:

$$E\{|S_k^n|^2\} = P_{kk}/|G_1|^2 \qquad (2)$$

The first switch SW1 is now connected to the kth antenna, the second switch SW2 is connected to the mth antenna, and the second switch signal path with gain G_{2A} is selected by connecting the third switch movable contact C3 to its first input p. The power P_{kmA} associated with gain G_{2A} at the transformer output with frequency bin index n is then measured, and it is given by:

$$P_{kmA} = E\{|G_1 S_k^n + G_{2A} S_m^n|^2\} \qquad (3)$$

$$\text{i.e. } P_{kmA} = |G_1{}^2 E\{|S_k^n|^2\} + |G_{2A}|^2 E\{|S_m^n|^2\} + 2\mathrm{Re}\{G_1 G^*_{2A} E\{S_k^n S_m^n *\}\} \qquad (4)$$

where Re{..} represents "real part of" and the asterisk "*" a complex conjugate. P_{kmA} is measured for all pairs of different antennas 12, i.e. for antenna index k = 1 to M-1 paired with m = k+1 to M respectively. This implies an antenna is not paired with itself. The value of P_{kmA} is measured by the DSP 28 in the same way as it measures P_{kk}, as previously described, and the same convention is adopted that the notation P_{kmA} is used in what follows to refer to the measurement.

Using the measured values of G_1, G_{2A} and the values of $E\{|S_k^n|^2\}$ and $E\{|S_m^n|^2\}$ computed above, a quantity x is now computed for each antenna pairing from:

$$x = (1/2)(P_{kmA} - |G_1|^2 E\{|S_k^n|^2\} - |G_{2A}|^2 E\{|S_m^n|^2\}) \qquad (5)$$

$$\text{i.e. } x = \mathrm{Re}\{G_1 G^*_{2A} E\{S_k^n S_m^n *\}\} \qquad (6)$$

In the same way, the procedure associated with Equations (3) to (6) is now repeated, except that the second switch signal path with gain G_{2B} is now selected by connecting the third switch movable contact C3 to its second input q to implement phase shift ϕ_3 instead of ϕ_2. The power P_{kmB} associated with gain G_{2B} at the transformer output with frequency index n is then measured for each antenna pairing, and equivalents of Equations (3) to (6) may be generated by replacing index A with index B. This enables a quantity y to be calculated from equivalents of Equations (5) and (6):

$$y = (1/2)(P_{kmB} - |G_1|^2 E\{|S_k^n|^2\} - |G_{2B}|^2 E\{|S_m^n|^2\}) \quad (7)$$

$$\text{i.e. } y = \mathrm{Re}\{G_1 G^*_{2B} E\{S_k^n S_m^n{}^*\}\} \quad (8)$$

The known complex value $G_1G^*_{2A}$ is now written as c + jd, and that of $G_1\ G^*_{2B}$ as e + jf, where j is the square root of -1. The next step is to compute the unknown complex value $E\{S_k^n S_m^n{}^*\}$ written as a + jb. Rewriting Equations (6) and (8) in terms of a to e and j:

$$x = \mathrm{Re}\{(c+jd)(a+jb)\} = ca - db \quad (9)$$

$$\text{and } y = \mathrm{Re}\{(e+jf)(a+jb)\} = ea - fb \quad (10)$$

Equations (9) and (10) are two simultaneous equations in two unknowns which are solved by standard methods to give the required values a and b, which in turn give $E\{S_k^n S_m^n{}^*\}$.

For example, for $G_1 = 1$, $G_{2A} = 1$ and $G_{2B} = j$ for $\phi = 90$ degrees, then c = 1, d = 0, e = 0 and f = -1, and a = x, b = -y.

The procedure associated with Equations (3) to (10) is repeated for each chosen pair of antenna index values k and m, and the corresponding value of $E\{S_k^n S_m^n{}^*\}$ is computed in each case. These two procedures yield a set of values $E\{|S_k^n|^2\}$ for k = 1 to M and $E\{S_k^n S_m^n{}^*\}$ for k = 1 to M-1 and m = k+1 to M which are known collectively as "covariance

terms". When arranged in a square array with E{| S_k^n |²} terms on the array diagonal (row k and column k) and each E{ $S_k^n S_m^n$ * } term at a respective row position k and column position m, this set of values is known as the "spatial covariance matrix". The entire process may be carried out independently for each DFT frequency bin, i.e. each value of transformer output index n.

Using some or all of the covariance terms in the spatial covariance matrix, the bearing (or angle of incidence or arrival) of one or more received signals may be estimated using standard techniques: see e.g. H L Van Trees "Optimum Array Processing" (part IV of "Detection, Estimation and Modulation Theory"), Wiley, New York, 2002, which discloses for example the MUSIC algorithm and least squares fitting. This is well known in the art of direction finding and will not be described.

Signal power received by antennas 12 may fluctuate: because of this it is advantageous to carry out averaging in connection with the measured quantities P_{kk}, P_{kmA} and P_{kmB} defined above. It is convenient to define a "commutation cycle" as consisting of a cycle of collecting data as described above from each of the settings b to e, p to r, of the three switches SW1, SW2 and SW3 required to determine P_{kk}, P_{kmA} and P_{kmB} for one value of the frequency bin index n. Further data is then collected using additional commutation cycles, each cycle giving a respective set of values of P_{kk}, P_{kmA} and P_{kmB}. The resulting multiple values of P_{kk}, P_{kmA} and P_{kmB} are then used to provide average values of each. These averages are then used in Equations (1) to (10) above.

The rate at which commutation cycles are carried out is referred to herein as the "commutation cycle rate". One or more of the signals received by the antennas 12 may contain periodic fluctuations, if for example data symbols are carried by a signal at a particular rate. If the period of the fluctuations is equal or close to a multiple or sub-multiple of the commutation cycle rate, then covariance terms derived as described above may be subject to consistent or systematic errors (known as "biases"). These may result in errors in estimated angles of incidence. To avoid this problem, the order in which the commutation (switch setting) is performed within each commutation cycle may advantageously be varied in a random or pseudo-random sequence between successive cycles.

Equations (1) to (10) above may be re-evaluated for other values of the frequency bin index n, e.g. adjacent frequency bands corresponding to index n-1 and n+1. Output bearing estimates are then obtained for various values of n and are combined to give an estimate for which error limits can be calculated.

A simulation was made of a direction finding system 10 of the invention having four antennas 12 in a square array. The simulation envisaged two emitters with identical carrier frequencies to be located in bearing in the plane of the antenna array. The emitters were treated as both transmitting at 6.25ksymbol/sec with a modulation type of QPSK, as described by R E Ziemer and R L Peterson, "Introduction to Digital Communication", Maxwell Macmillan International, New York, 1992. They were at respective bearings or angles of arrival of 30° and 70° at the antenna array relative to a predefined reference direction. The signal to noise ratio (emitted signal power divided by total noise power over 25.6MHz bandwidth) was assumed to be high. The sampling rate was 25.6MHz and a block of 4096 samples were collected, a Hamming window was applied (see Oppenheim *et al.* mentioned above), and the result was processed by discrete Fourier transform. The sample collection time was 0.16 milliseconds, which corresponds to one emitter symbol period. If only one block of samples were to be processed, results are poor, because signals are highly correlated over the sample collection time. First and second blocks of samples were collected with an intervening time interval corresponding to at least three symbols to avoid this. Emitters of interest often contain a root raised cosine (RRC) pulse shaping filter which is shorter than this intervening time interval, in which case there is no correlation between signals in the sample blocks. The overall covariance matrix was then derived using parameters obtained using Equations (1) to (10) for both data blocks and averaging. Matrix elements were processed using the known MUSIC algorithm (see Van Trees mentioned above) to determine emitter bearings. This algorithm is neither the only nor even the best algorithm for this purpose, but it is simple and often suggested for that reason.

Figure 2 is a graph of MUSIC spectrum against angle of arrival (AoA) derived from covariance matrix elements obtained using the method of the invention. It shows reasonably well-defined peaks 40 and 42 at angles of arrival of 30° and 70°, showing that the simulated emitters have been located.

For comparison, a trial was made of the single receiver technique disclosed by C M S See, "High Resolution DF with a Single Channel Receiver", 0-7803-7011-2/01 IEEE 2001. Using the same parameters and MUSIC algorithm processing, this technique gave the results shown in Figure 3. Here the emitter at 30 degrees has not been resolved, and the 70 degree emitter has been resolved at 50, but with a peak height ~15x smaller than the peak 42 (NB Figures 2 and 3 have axes with different scales).

For completeness the conventional method (which requires one receiver per antenna) was also simulated using the same parameters and MUSIC algorithm processing. This method gave the results shown in Figure 4. It shows very well defined peaks 60 and 62 at angles of arrival of 30° and 70°, showing that the simulated emitters have been located with better accuracy than the invention, but this is at the expense of using one receiver per antenna instead of one receiver only for all antennas.

Claims

1. A direction finding system incorporating a plurality of antennas (12) characterised in that the system (10) also includes:

   a) means (SW1) for determining individual antenna signal strengths;

   b) combining means (SW2, P2, P3, SW3, 18) for deriving combined antenna signal strengths by forming combinations of first and second antenna signals derived from different antennas (12), wherein the second antenna signals are in two sets with signals in one set having a non-zero phase difference relative to signals the other set; and

   c) means for deriving covariance matrix elements from antenna signal strengths and for determining at least one emitter bearing therefrom.

2. A direction finding system according to Claim 1 characterised in that the relative phase difference is in the range 30 to 120 degrees, and the means (SW1) for determining individual antenna signal strengths and the combining means (SW2, P2, P3, SW3, 18) are arranged to enable successive signal strengths to be derived in successive steps.

3. A direction finding system according to Claim 2 characterised in that the relative phase difference is substantially 90 degrees.

4. A direction finding system according to Claim 3 characterised in that the combining means (SW2, P2, P3, SW3, 18) is arranged to combine antenna signals with equal gain magnitude and with equal and unequal phase.

5. A direction finding system according to Claim 1 characterised in that the combining means incorporates phase shifting means (P3) switchable into and out of an antenna signal path.

6. A direction finding system according to Claim 1 characterised in that the combining means incorporates an adder (18) having two inputs both switchably connected to individual signal paths extending to respective antennas (12).

7. A direction finding system according to Claim 1 characterised in that:

   a) the means for determining individual antenna signal strengths comprises a first multipole switch (SW1) having input poles (b, c, d, e) connected to receive signals from respective antennas (12);

   b) the combining means (SW2, P2, P3, SW3, 18) incorporates a second multipole switch (SW2) having input poles (b, c, d, e) connected to receive signals from respective antennas (12) and a third multipole switch (SW3) for switching phase shifting means (P3) into and out of an antenna signal path extending via the second multipole switch (SW2); and

   c) the combining means (SW2, P2, P3, SW3, 18) also incorporates adding means (18) for combining signals, the adding means being arranged to add an antenna signal in a first signal path extending via the first multipole switch (SW1) to another antenna signal in a second signal path extending via the second and third multipole switches (SW2, SW3).

8. A method of direction finding using a plurality of antennas (12) characterised in that the method incorporates:

   a) determining individual antenna signal strengths;

   b) determining combined antenna signal strengths by forming combinations of first and second antenna signals derived from different antennas (12), wherein the second antenna signals are in two sets with signals in one set having a non-zero phase difference relative to signals the other set; and

   c) deriving covariance matrix elements from antenna signal strengths and determining at least one emitter bearing therefrom.

9. A method according to Claim 8 characterised in that the relative phase difference is in the range 30 to 120 degrees and successive signal strengths are determined in successive steps.

10. A method according to Claim 9 characterised in that the relative phase difference is substantially 90 degrees.

11. A method according to Claim 10 characterised in that the step of forming combined antenna signal strengths combines antenna signals with equal gain magnitude and with equal and unequal phase.

12. A method according to Claim 8 characterised in that the step of forming combined antenna signal strengths includes switching phase shifting means (P3) into and out of an antenna signal path.

13. A method according to Claim 8 characterised in that the step of forming combined antenna signal strengths includes adding signals in signal paths extending switchably to different antennas (12).

14. A method according to Claim 8 characterised in that:

    a) the step of determining individual antenna signal strengths comprises switching signals from antennas (12) via a first path;

    b) the step of forming combined antenna signal strengths incorporates:

        i) switching signals from antennas (12) via a first path for combining;

        ii) switching signals from antennas (12) via a switch selectable second path or a third path for combining, the third path being arranged to phase shift antenna signals therein relative to antenna signals in the second path; and

        iii) adding a first path antenna signal to second and third path antenna signals individually.

ABSTRACT

Direction finding by radio comprises arranging an array of antennas (12) to receive signals from emitters, selecting individual antenna signals using a first multipole switch (SW1) and determining antenna signal strengths. Individual antenna signals are also selected by a second multipole switch (SW2), which routes a selected signal to a third multipole switch (SW3). The third switch (SW3) switches a phase shifter (P3) into and out of an antenna signal path. An adder (18) is employed to add an antenna signal in a first signal path extending via the first multipole switch (SW1) to a different antenna signal in a second signal path extending via the second and third switches (SW2, SW3). This determines combined signal strengths between pairs of antenna signals, one of which either has or has not been relatively phase shifted depending on the third switch position. Covariance matrix elements are determined from signal strengths enabling emitter bearings to be derived.

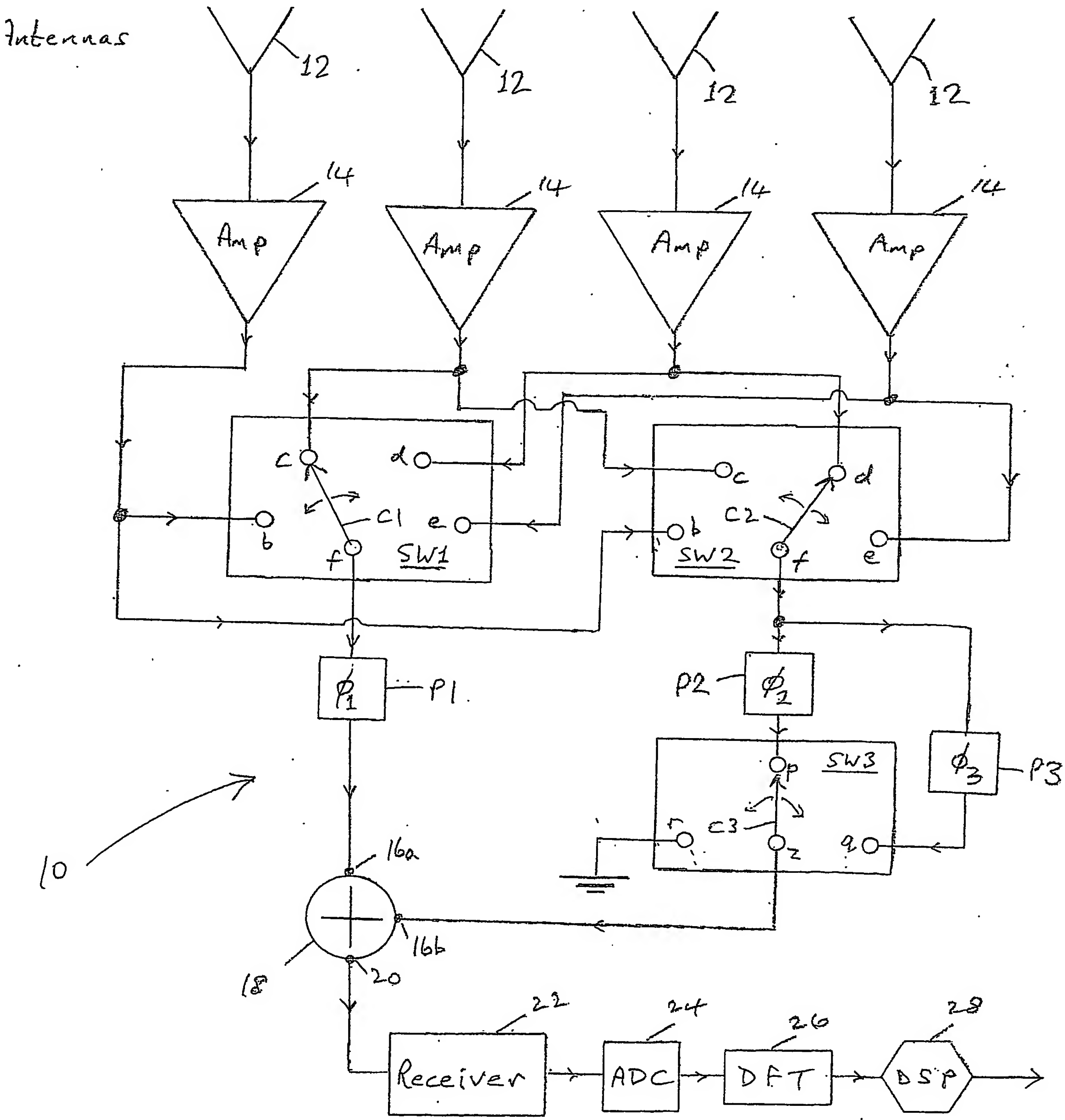
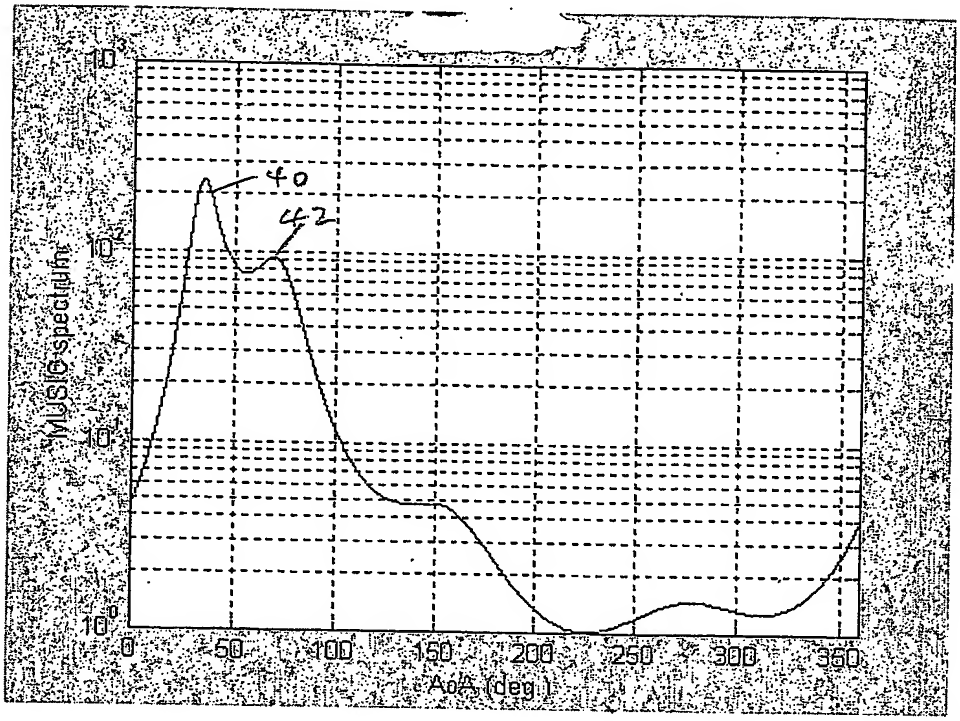

Antennas
12
12
12
12
14
14
14
14
Amp
Amp
Amp
Amp
c
d
b
c1
e
f
SW1
c
d
b
c2
f
e
SW2
P1
P1
P2
ϕ_2
ϕ_3
P3
p
SW3
r
c3
z
q
10
16a
16b
18
20
22
24
26
28
Receiver
ADC
DFT
DSP

FIGURE 1



10^3
10^2
10^1
10^0
MUSIC spectrum
40
42
0
50
100
150
200
250
300
350
AoA (deg.)

FIGURE 2

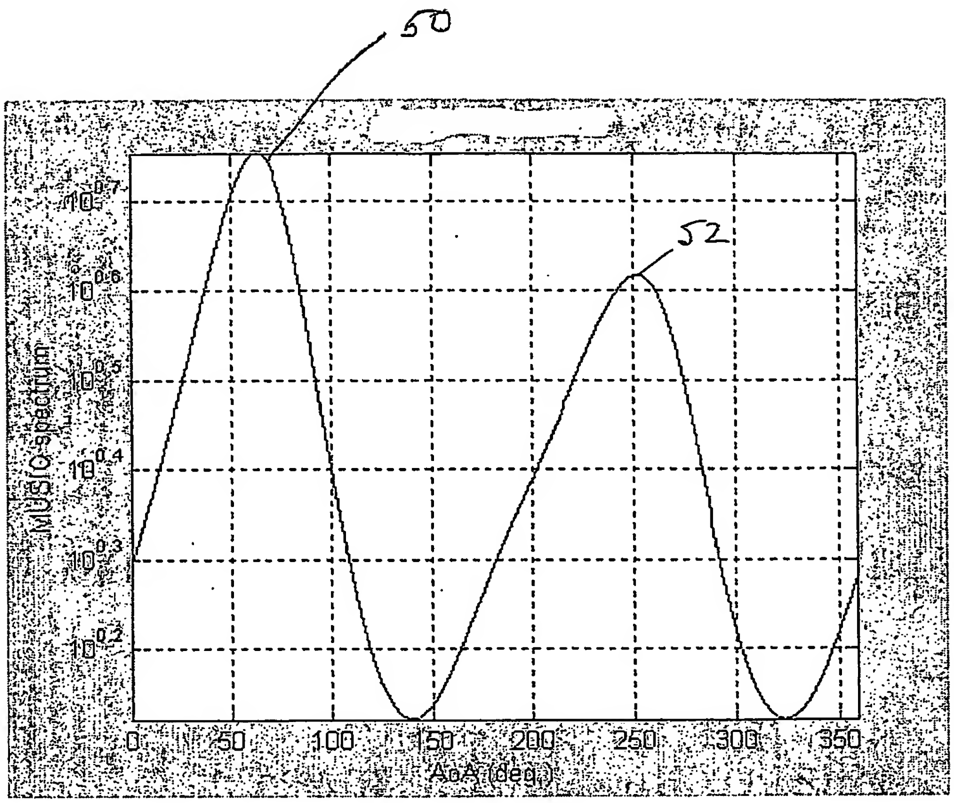

50
52
MUSIC-spectrum
10^0.7
10^0.6
10^0.5
10^0.4
10^0.3
10^0.2
0
50
100
150
200
250
300
350
AoA (deg.)

FIGURE 3

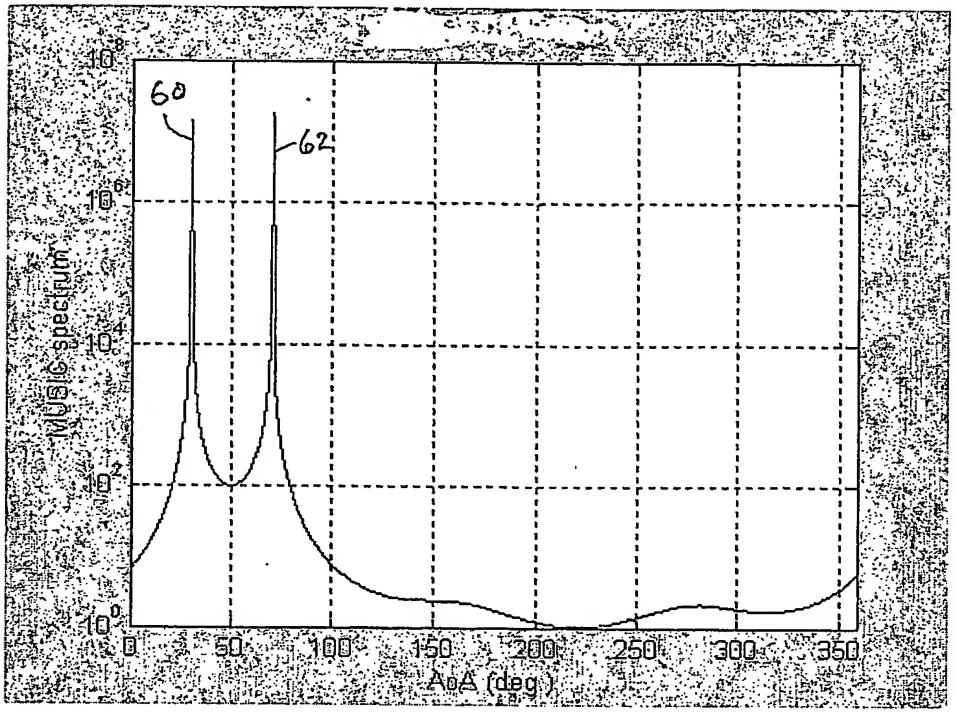

10^8
10^6
10^4
10^2
10^0
MUSIC spectrum
60
62
0
50
100
150
200
250
300
350
AoA (deg.)

FIGURE 4

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